ROOT GROWTH AND SOIL STRENGTH IN CONSERVATION AND CONVENTIONAL TILL COTTON

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ABSTRACT

Corn (*Zea mays* L.), soybean (*Glycine max* L. Merr.), and wheat (*Triticum aestivum* L.) have shown inverse linear relationships between average soil strength within the top 2 feet of the profile and yield in Coastal Plain soils that have subsurface hard layers. We tested this relationship for cotton (*Gossypium hirsutum* L.) hypothesizing that root growth and lint yield of cotton would be greater with annual deep tillage. Effects of surface tillage, deep tillage, and rye (*Secale cereale* L.) cover crop were evaluated. Reduction of root growth was correlated ($r^2 = 0.66$) with mean soil strength or with the 95th percentile of soil strength distribution, which acted as a stabilized, surrogate measurement of maximum strength that cotton roots would encounter. Cotton lint yield was not reduced by the treatments, even though root growth decreased with increasing soil strength. Lack of tillage treatment effects on yield may have been the result of management practices that employed a small disk in conventionally treated plots and maintained traffic lanes in all plots. Both of these practices would help prevent re-compaction. These management practices may help reduce the frequency of subsoiling while maintaining viable production practices for cotton grown in traditionally wide (38-in) rows.

KEYWORDS

Subsoiling, Hardpan, Cotton, Root growth, Deep tillage

INTRODUCTION

Recent studies have shown inverse linear relationships between soil strength and yield of corn, soybean, and wheat grown on southeastern Coastal Plain soils that have hard subsurface layers (Frederick *et al.*, 1998; Busscher *et al.*, 2000). Yield increases were attributed to the use of a paratill® to disrupt the hard layer and planting in narrow rows. These results agreed with earlier, more general recommendations that Coastal Plain soils be deep tilled annually (Threadgill, 1982) and went a step further by showing that deep tillage twice a year increased yield even more for double-cropped wheat and soybean production. Compaction, characterized by the high soil strength, reduced crop yields but was alleviated by deep tillage. These recent studies were conducted to quantify the amount of yield reduction that compaction would cause and to develop a relationship between yield and strength.

Cover crops, such as rye, have been reported to prevent or reduce the severity of compaction. They appeared to reduce compaction or re-compaction by minimizing the effects of machinery traffic or by perforating hard layers with deep root growth when water contents within the hard layer were favorable for growth (Ess *et al.*, 1998; Raper *et al.*, 2000; Rosolem *et al.*, 2002).

The relationship between soil strength and cotton yield in controlled traffic systems with traditional wide (38-in) row management is unknown, but we hypothesized that root growth and lint yield would increase as soil strength decreased. We tested this hypothesis in a two-year study using surface tillage with a disk, deep tillage with an in-row subsoiler, and rye cover crop treatments to provide a range of soil strengths.

MATERIALS AND METHODS

This project was first reported at the Southern Conservation Tillage Conference in 1998 when we presented information on cover crop vs soil strength characteristics (Busscher and Bauer, 1998). This presentation focuses on the relationships among tillage, root growth, and yield. The methods as reported earlier are reviewed and extended for the additional aspects discussed. In 1990, rye cover crop plots for cotton production were established at the Clemson Pee Dee Research Center near Florence, SC. Between then and 1992, half of the plots were converted from conventional to conservation tillage (Bauer and Busscher, 1996). In 1993, all plots were subsoiled and planted to cotton which was not harvested because of drought. In 1994 and 1995, the plots were split to accommodate deep tillage treatments (in-row subsoiling and not subsoiling). Treatments included fallow or rye winter cover, disked or non-disked surface tillage, and deep tillage or no deep tillage.

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The experimental design was split-split plot, randomized complete block design with three replicates. Main plot treatments were winter cover, subplot treatments were surface tillage, and subsubplot treatments were deep tillage. Subsubplots contained four 38-inch wide rows that were 50-feet long. The plots were located on a Norfolk loamy sand (fine, loamy, siliceous, thermic, Typic Kandiudult).

In October 1993 and 1994, after cotton stalks were shredded, half of the plots were seeded to rye at 110 pounds of seed acre^{-1} in 7.5-inch rows using a John Deere 750 grain drill. In early May of the following year, plots that were to be surface tilled were disked with a 10-foot wide disk harrow (Tufline Mfg. Co., Columbus, GA); plots that did not receive surface tillage were desiccated with paraquat (1,1'_dimethyl_4,4'_bipyridinium).

In a separate operation prior to planting, half the subsubplots were subsoiled within 6 inches of the previous year's rows with a KMC four-row subsoiler. In mid-May, plots were seeded to cotton ('DES 119') over the subsoiled areas with a four-row Case-IH 900 series planter equipped with Yetter wavy coulters. Wheel tracks and row positions were maintained by centering equipment within plots guided by range poles.

Nitrogen (80 lbs N acre^{-1} as ammonium nitrate) was applied in a split application - half at planting and half one month later. Nitrogen was banded approximately 2 inches deep and 6 inches from the rows. Lime, P, K, S, B, and Mn were applied as needed based on soil test results and Clemson University Extension recommendations. Weeds were controlled with a combination of herbicides, cultivation in only the disked plots, and hand-weeding. Insects were controlled by applying aldicarb (0.75 lbs ai acre-1) in furrow for thrips [*Frankliniella occidentalis* (Pergande)]; other insecticides were applied as needed.

Soil cone index was measured in each subsubplot in early June with a 0.5-inch diameter, 30° solid angle cone tip attached to a hand-operated, recording penetrometer (Carter, 1967). Soil cone index was measured to a depth of 22 inches at nine positions across a mid-plot row (from non-traffic midrow to traffic midrow). Each measurement was the mean of three probings within each subsubplot. Cone indices in the form of analog data were recorded on index cards and subsequently digitized (Busscher *et al.*, 1986b). Data were normalized using a log transformation before making any statistical analyses (Cassel and Nelson, 1979).

When cone index data were collected, soil water contents were measured gravimetrically in 4-in depth increments within non-wheel-track mid row and in-row positions. These measurements were considered representative of water contents for each subsubplot.

In early August, in-row root growth was measured by collecting two one-inch diameter core samples from each plot to a depth of three feet. The two cores from each plot were combined and subjected to hydropneumatic elutriation which used flowing water and compressed air to separate roots from soil and to deposit them on a fine screen (Smucker *et al.*, 1982). Roots were then stained methyl violet blue, floated on water in a transparent tray, and counted with an automated digitizer (Delta-T Devices, Ltd., Burwell, Cambridge, England). All roots, primary and laterals, were counted together. Root data were not lengths but associated counts based on digitization of the root image (Harris and Campbell, 1989; Busscher *et al.*, 2001).

In mid to late October, cotton was chemically defoliated. In early November, seed cotton yield was harvested from the two interior rows using a two-row spindle picker and bagged. Each harvest bag was subsampled and the subsample was saw-ginned to measure lint percent. Lint percentage was multiplied by seed cotton yield to estimate lint yield.

Statistical differences among the data were determined using ANOVA and the LSD mean separation procedure (SAS Institute Inc., 2000). Differences were considered statistically significant at the 5% level unless otherwise specified.

Table 1. Cone indices, water contents, and cone indices corrected for water content differences listed by depth for the top 22 in of the horizon.

	Cone index (CI)		Water content		Corrected CI‡	
Depth	1994	1995	1994	1995	1994	1995
inches	-------- Atm --------		- lbs (100 lbs soil)$^{-1}$ -		---- Atm ----	
2	10.3 f†	8.9 e	5.8 e	10.6 c	8.7	10.8
6	21.7 e	18.6 d	6.0 de	10.0 d	18.6	21.6
10	36.1 d	24.5 c	6.8 c	10.0 d	33.0	28.5
14	57.1 a	38.5 a	6.6 cd	10.2 cd	51.3	45.5
18	46.0 b	30.3 b	8.3 b	11.6 b	47.1	39.8
22	41.6 c	31.3 b	10.3 a	12.9 a	49.5	45.4

† Means by year with the same letter are not different based on $LSD_{0.05}$.

‡ Cone indices corrected to a water content of 10 lbs (100 lbs soil)$^{-1}$

RESULTS AND DISCUSSION

SOIL WATER CONTENTS

For both years, water contents differed only for depth and for depth by cover by surface tillage interaction. Water contents generally increased with depth (Table 1). The depth by cover by surface tillage interaction showed differences in the lower foot of the profile. There, fallow by disked and rye by non-disked interactions had greater water contents than rye by disked and fallow by non-disked interactions.

Water contents in the upper half (top foot) of the profile differed by depth only in 1994. All other effects for the top foot were not significant. To avoid complications with water content, some tillage and root growth analyses with cone index were limited to the top foot of the profile.

Though water content data did not generally vary with treatment, when all depths were averaged together, water content and soil strength were correlated (Fig. 1). This relationship provided a way to compare cone indices measured at different water contents by permitting adjustment of cone indices to values they would have had if measured at a single water content.

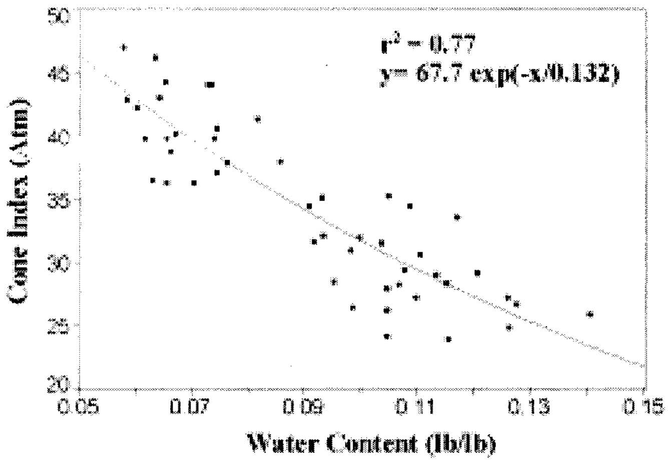

Fig 1. Regression of soil cone index as a function of water content used to correct cone indices to a common water content.

DEPTH

For both years, cone index increased with depth to the hard layer at about 14-in below the surface. Below the hard layer, cone index decreased with depth (Table 1 and Fig. 2). Increases in cone index readings above the hard layer (above 14 in) were actual increases in soil strength because they were accompanied by increases in water content. Decreases in cone index reading below the hard layer were also accompanied by increases in water content and may have been due to the increasing water content. However, after correction of the cone indices to a common water content (Table 1), cone indices still decreased below the hard layer showing that the highest strength was still at the 14-in depth which was the hard pan.

POSITION

Cone indices within the top foot varied with position across the row. Cone indices were lower under the non-wheel-track mid row (Fig. 2, position = 0 in) than under the wheel-track mid row (position = 38 in). Differences between non-wheel-track and wheel-track mid rows were greater for tilled treatments than for non-tilled treatments (Fig. 2) presumably because the tilled-treatment compaction was loosened and recompacted annually while the non-tilled-treatment compacted continuously from year to year (Busscher *et al.*, 2001). As expected, the lowest cone indices were found at mid rows (position = 19 in) because of soil loosening associated with deep tillage or residual loosening from tillage of previous years.

TILLAGE

Within the top foot, cone indices were lower for treatments that were disked or deep tilled than for those that were not tilled (Table 2). Cone indices decreased from treatment to treatment as more tillage was practiced. Deep-tilled treatments had lower cone indices than non-deep-

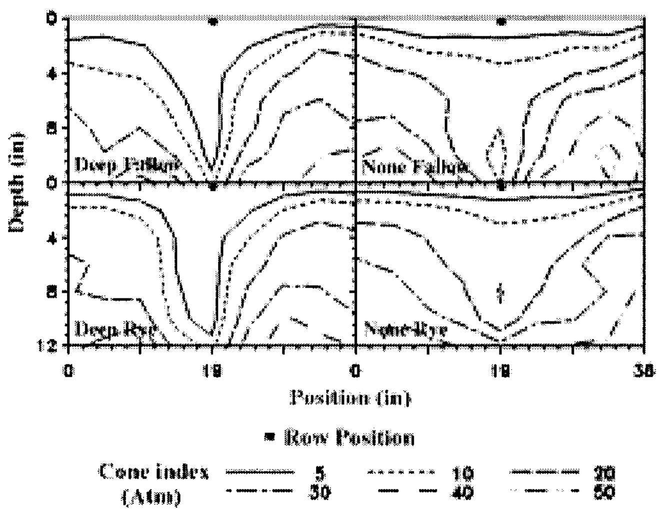

Fig. 2. Contours of cone index as a function of depth into the profile and position across the row averaged over disked and non-disked treatments in 1995. Labels are for deep tillage or none and fallow or rye winter cover.

Table 2. Mean cone index by tillage treatment for the top foot of the soil.

	Surface Tillage		
Deep Tillage	Disked	Non disked	Mean
	---------- Atm ----------		
1994			
Subsoiled	20.8	21.8	21.3b
None	22.9	30.6	26.5a†
Mean	21.8b†	25.8a	
1995			
Subsoiled	14.1	16.2	15.1b
None	20.8	25.2	22.9a†
Mean	17.2b‡	20.2a	

† Means with the same letter are not significantly different at 5% using the LSD mean separation procedure.

‡ Means with the same letter are not significantly different at 10% using the LSD mean separation procedure.

tilled treatments; disked treatments had lower cone indices than non-disked treatments. Disked and deep tilled treatments had the lowest cone indices. Soil cone indices in the top foot were not different for the cover crop vs. fallow treatments.

More tillage and lower cone indices did not lead to differences in yield (Busscher and Bauer, 1998). One reason for this could be the residual effect of the previous year's tillage. Perhaps, it was sufficient to maintain a suitable soil environment for cotton growth. The residual loosening can be seen in the center of the zone of measurement of Fig. 2, even in the treatments that had not been deep tilled for two years. In most cases, residual loosening would not be enough to maintain proper growth as seen by standard recommendations for annual tillage in these soils (Threadgill, 1982). However, in this study, there appeared to be less reconsolidation than in other studies (Busscher *et al.*, 1986a). This may have occurred because we used the same wheel tracks to prevent re-compaction by wheel traffic and because we used a relatively small disk that did not produce a disk pan (Fig. 2).

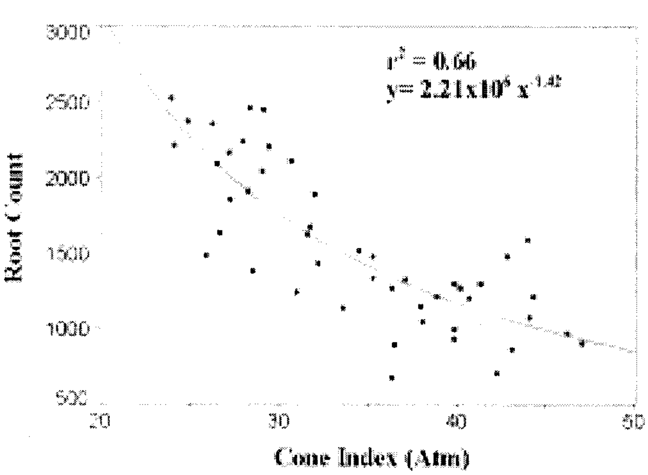

Fig. 3. Root count as a function of mean profile soil strength. Mean strength was taken over the top 2 feet of the profile and across a row.

Root Growth

Root growth was correlated with soil strength. Though root growth was measured only under the row, it correlated better with mean cone index across the whole profile (r^2 = 0.66, Fig. 3) than with the cone index measured only under the row (r^2 = 0.51). Correlation with cone index across the profile was consistent with recent findings where roots encountering high soil strength slowed shoot growth (Mulholland *et al.*, 1999; Roberts *et al.*, 2002). It is not surprising that root growth might be slowed as well.

We found similar results when correlating root growth with the maximum cone index that the roots would encounter. We used the 95th percentile of cone index rather than the maximum measured data point to represent the maximum cone index that the root might encounter because it was a more stable number. The maximum measured data point was the result of only one measurement while the 95th percentile was the result of all the data, calculated by adding the mean and two standard deviations. Root growth was marginally better correlated to the 95th percentile of cone index (r^2 = 0.68) than to mean profile cone index. Root growth was not correlated to yield.

Cover

The rye cover crop treatment resulted in lower cotton lint yield in 1994, but that was expected because of difficulty planting into it. The cover crop also did not have a significant effect on soil water content, presumably because of high seasonal rainfall for 1994 and 1995 (51 in and 57 in compared to the 120 year average of 45 in). When rainfall is limiting, cover crops can increase soil water content by increasing infiltration and decreasing evaporation or decrease it by using soil water for transpiration. The cover crop in this study also did not show any consistently significant differences with cone index data.

CONCLUSIONS

The rye winter cover crop had no effect on soil strength or yield under conditions of this study. This response differed from previous studies where rye cover increased yield within conservation tillage on these same soils when rainfall was lower (Bauer and Busscher, 1996).

Cone index continued to increase if soils were not deep tilled each year. Root growth decreased as soil strength increased. The reduction in root growth had the best statistical relationship with either the mean soil strength across the whole profile or the 95th percentile of soil strength. The latter acted as a stabilized, surrogate measure of the maximum strength that the cotton roots would encounter.

Yield was not related to soil strength in this study suggesting that not subsoiling for at least two years may be a viable production practice for cotton grown in traditionally wide rows using controlled traffic. Yield limiting soil strengths may have been partially prevented by our use of a small disk harrow; use of heavier equipment may not produce the same effect. Additional research on the frequency of deep tillage and degree of re-compaction that reduces cotton lint yield are needed to insure that this can be a reliable production practice.

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We thank E.E. Strickland and B.J. Fisher for technical support. Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agric. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

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